PREDICTING THE PRESENCE OF FILAMENTOUS ALGAE FROM COTTAGER PERCEPTIONS AND LAKE CHARACTERISTICS:

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PREDICTING THE PRESENCE OF FILAMENTOUS ALGAE FROM COTTAGER PERCEPTIONS AND LAKE CHARACTERISTICS: AN EXPLORATORY STUDY

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ASTRACT

In 1986, over five thousand cottagers on 214 Central Ontario lakes were surveyed via questionnaire on the extent of the shoreline of their respective lake affected by filamentous green algae (primarily metaphytic growths of members of the Zygnematales). Accuracy of cottager perceptions were determined by comparison to field survey data of algal growths at 32 of the lakes. A predictive model based upon cottager perceptions was able to classify lakes according to algal abundance with over 90% accuracy. Cottager perceptions were concluded to be useful as a low cost method for surveying the extent of algal growth in many lakes over a wide geographic range in a small time frame.

Water chemistry data for 191 of the 1986 survey lakes was compared to the cottager algal abundance estimates to determine if water chemistry could be used to predict algal abundance. Discriminant analyses results indicated that coarse scale algal abundance could be accurately predicted in over 60% of the lakes on the basis of water chemistry parameters. The discriminant analysis models were then applied to water chemistry data from larger lake data bases (735 and 5,276 lakes). A 1988 field survey of algal abundance in 44 lakes determined that over 60% of the lakes in each of the three databases were correctly classified according to algal abundance by the water chemistry models.

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INTRODUCTION

Evidence from a fairly broadly based collection of studies has indicated that filamentous green algae (FGA) regularly become more abundant in lakes whose pH is dropping over time (Stokes, 1986). Under acidified conditions, FGA can become the dominant feature in the littoral zone of a lake. The abundance of FGA has been monitored at a variety of acidified lakes by the Ontario Ministry of the Environment as part of the Acidic Precipitation in Ontario Study (APIOS) program (Turner et al., 1987; Howell et al., 1990; Jackson et al., 1990; France & Welbourn, 1991). Epilithic, epiphytic, and metaphytic FGA were present in littoral zones. The major metaphytic FGA in lakes of pH 6.8 or lower was Zygogonium tunetanum Gauthier-Lievre (Wei et al., 1989). The growth of Zygogonium and other FGA genera frequently reached nuisance proportions by interfering with cottagers' enjoyment of the lakes (France & Welbourn, 1991). The phenomenon may represent a serious acidification related socioeconomic problem in the region.

The purpose of the present study was to utilize perceptions and observations of cottagers as a low cost method for surveying the extent of FGA growth in a large collection of lakes. Cottager estimates of algal cover along shorelines were then applied to water chemistry data to determine if water chemistry could be an indicator of FGA abundance. Field surveys of FGA abundance were performed on several occasions to verify model predictions.

MATERIALS AND METHODS

1985 Cottager Survey

In August 1985, approximately 200 cottagers residing at ten softwater lakes in Ontario were given questionnaires on nuisance algal blooms. At each lake, a target number of cottages was determined to represent the lake. On large lakes, the sample size was set at 30 cottages. On small lakes, all cottages were included in the sample. On large lakes, selection of cottages was systematic: questionnaires were distributed to every third or fourth cottage, etc., to achieve the target number of cottages. The lakes were all situated on the Canadian Shield in the northern portions of Ontario watershed divisions 2E and 2H (Fig. 1) in the Parry Sound, Muskoka, Haliburton and Peterborough regions. The lakes were grouped into three qualitative categories according to the abundance of FGA as determined by previous field work. The categories were CONSIDERABLE (4 lakes), SOME (2 lakes) and NONE (4 lakes). Cottagers were provided with a description of typical FGA growths and asked if they had ever seen such growths at their lake in the summer of 1985 or previous years. If cottagers confirmed that they had seen such growths, they were asked to estimate how much of the lake had been affected. Cottagers were asked a series of related questions on algal abundance rather than just one. Factor analysis was applied to questionnaire results to verify that responses to related questions were correlated and the results had good structure (meaning that related questions were answered logically and consistently, see Kerlinger, 1979). Discriminant analyses were applied to the questionnaire data (responses to eight questions) and known lake FGA abundance in order to classify lake FGA status on the basis

of individual cottager perceptions (a similar style of application is presented by Gould (1988)).

1986 Cottager Survey

In June 1986, a larger scale mail - out survey was performed involving over 5,200 cottagers. The survey was conducted on 178 lakes (each with ten or more cottages), the original 10 lakes from the 1985 survey and an additional 26 lakes with evidence of filamentous or other nuisance algae. A total of 214 lakes were therefore involved in the 1986 survey. The subset of 178 lakes was randomly selected from within groupings of lakes based upon acid sensitivity and the completeness of available water chemistry data (Table 1). Field data provided known FGA status for 32 of the 214 lakes. In contrast to the 1985 survey, the abundance of FGA in these 32 reference lakes was quantified (CONSIDERABLE = >20% of shoreline affected; SOME = 5 to 20%; NIL = <5%; Table 2). All 214 lakes were located within watershed divisions 2E and 2H as in the 1985 survey (Fig. 1). Parry Sound, Nipissing, Muskoka, Haliburton, Victoria and Peterborough region lakes were included in the survey. The mail - out questionnaire contained essentially the same questions and was distributed in the same manner as the 1985 pilot survey. Discriminant analyses were applied to the questionnaire data (12 questions) and known lake FGA abundance (32 lakes) as in the 1985 survey. The 1986 survey data, however, were averaged for each lake (all cottager responses for that lake combined) prior to analyses. The discriminant analyses were also

applied to the remaining lakes (unknown FGA status) in the 1986 survey in order to predict FGA status for each of the 214 lakes.

Water Chemistry Databases

Water chemistry information was obtained from the Ontario Acid Sensitivity Database (Neary et al., 1990) for three different groups of lakes as described below.

Water Chemistry Database I

Acceptable water quality data (at least one sample taken between 1981 and 1987) were available for 191 of the 214 lakes involved in the 1986 cottager survey. The predicted FGA status for each of those 191 lakes was compared to a collection of morphometric, location and water chemistry variables (Table 3, some variables with skewed distributions transformed by $\log_{10}$) via discriminant analysis to determine if those variables could classify lakes on a fine scale incorporating CONSIDERABLE, SOME, and NIL groupings (as in 1986 survey) or simply on a coarse scale involving SOME (>5% shoreline affected) and NIL (<5%) only. The Stepwise WILKS method was used in the discriminant analyses (Norusis, 1988). Eight different discriminant models were tested as outlined in Table 4.

Water Chemistry Database II

One of the discriminant analyses (Model 3) was then applied on a database of 735 lakes in Ontario (including the original 191 lakes). The 735 lakes were located in watershed divisions 2D, 2E, 2H, 2K and 2J (Fig. 1). The 735 lakes were not randomly selected; they

were chosen on the basis of sufficient available water chemistry data to utilize the long list of variables (Table 3).

Water Chemistry Database III

Finally, a 5,276 lake database (including the 735 lakes) was classified on the basis of the Model 7 discriminant analysis (which utilized the short list of variables, Table 3). The lakes were located in watershed divisions 2A, 2B, 2C, 2D, 2E, 2H, 2J, 2K, 2L, 2M, 4C, 4D, 4F, 4G, 4J, 4K, 4L, 4M, 4N, 5P, 5Q and 5R (Fig.1) which covered most of the central portion of Ontario.

Summary of Databases and Statistical Tests

Fig. 2 is a flow chart which describes the order in which the various databases were analyzed.

1988 Field Survey

An aerial survey (via low altitude helicopter flights) of 44 lakes was undertaken in the summer of 1988 which visually estimated the percentage of shoreline affected by FGA in each lake. 36 of those lakes were part of Database II and all 44 were part of Database III.

RESULTS

1985 Cottager Survey

Over 75% of the cottagers completed the 1985 survey and returned questionnaires by October 1985. Overall, the data showed good evidence of careful completion by respondents and good structure (related questions were answered logically and consistently, see Kerlinger, 1979). The prediction by cottagers of conditions with respect to FGA at the ten lakes was highly accurate. Discriminant analyses correctly classified up to all 10 of the lakes on the basis of responses by cottagers to eight questions on FGA abundance.

1986 Cottager Survey

Over 80% of the cottagers responded to the 1986 survey by September 1986. Cottager perceptions were once again very useful in classifying lakes according to FGA abundance. 31 of the 32 lakes for which FGA status was known were correctly classified by discriminant analysis into NIL, SOME or CONSIDERABLE groups on the basis of cottager responses to twelve survey questions. Discriminant analysis predictions for the lakes in the 1986 survey (214 lakes) indicated 16.1% should have had CONSIDERABLE FGA growth, 31.6% should have had SOME FGA growth and 52.3% should have had NIL FGA growth. In other words, according to predictions based on cottager perceptions, approximately half of the lakes should have been affected by FGA accumulations.

Database I

Results of discriminant analysis on the classification of lakes from water chemistry Database I on the basis of environmental variables are presented in Table 5. The coarse scale classification models (Model 3 and Model 7) provided the highest percentage of correctly classified lakes (compared with the original cottager classifications). Even though Model 3 was set up as a two function model, during the analysis of data from Database I, all of the variance was accounted for in a single function (Table 6); hence there is a single axis scatter plot for this model (Fig. 3A). The Model 3 classification considered that all lakes with a positive Axis 1 score would be NIL group lakes, yet many of the actual NIL group lakes as classified by cottager perceptions (circles in Fig. 3A) had negative Axis 1 scores. Conversely, many of the true SOME group lakes (triangles in Fig. 3A) had positive Axis 1 scores. Model 7 was a single function (single Axis) model and the scatter plot of the Database I lake axis scores closely resembled the Model 3 figure (Fig. 3B). Only three variables were required to define Axis 1 for Model 7 (Table 6).

The misclassification of the true (cottager) groupings of the lakes in Database I by Models 3 and 7 was reflected in the low percentages in Table 5 and the wide scatter of lake scores (both NIL and SOME group lakes) along Axis 1 of the scatter plots (Fig. 3).

Database II

The Model 3 results predicted that 35% of the Database II lakes would have FGA accumulations (Table 7). A geographical categorization of results is provided in Fig. 4. Of the five major watersheds involved, three (2D, 2E and 2H) showed a high incidence of predicted presence of FGA (Table 7). The three watersheds were in the areas of Sudbury, Muskoka and the Kawarthas (Fig. 1).

Database III

The Model 7 results predicted that 19% of the lakes in Database III would have FGA accumulations (Table 8). A geographical categorization of results is provided in Fig. 5. The far left column of quadrants in Fig. 5 represent an area between longitude 95° 00′ and 90° 00′ (arrow). In order to reduce map distortions due to the earth's curvature, these larger quadrants were not drawn to scale. Lakes predicted to have FGA were largely concentrated in the areas where Database I lakes were and the area between Sudbury and Sault Ste. Marie. No lakes were predicted to have FGA in the more northerly portions of the province.

1988 Field Survey

Model 7 predictions were accurate for 27 (61%) of the 44 lakes surveyed by helicopter (Table 9). 24 (66%) of the 36 lakes in the helicopter survey belonging to Database II had their FGA status correctly predicted by Model 3.

DISCUSSION

Predictive models based upon cottager perceptions of FGA abundance in central Ontario lakes were consistently reliable and achieved a 90% or better accuracy in 1985 and 1986. On the basis of this accuracy, classifications derived from cottager observations were considered to be the equivalent of the true status of FGA for lakes in Database I. The development of the objectively based Model 3 and Model 7 lake classification discriminant analyses with Database I (classified as per cottager perceptions) predicted that over 60% of the lakes analyzed by the models could be correctly classified for FGA abundance (Table 5, Fig. 3). The 1988 helicopter survey verification of the Model 7 results also showed an over 60% correct classification rate for that model (Table 9). In other words, predictions based upon cottager perceptions almost exactly matched the results of field surveys by trained technical staff. It should not be lost on the reader that cottager models were better FGA predictors than was Model 7 (≈90% accuracy versus ≈60% accuracy). The actual cottager predictions were not always accurate in themselves, but when combined in a model of both accurate and misperceived lake characteristics, cottager perceptions became a basis for highly accurate model predictions.

The success of the cottager models, however, should not cause one to overlook the more objective models. The variables chosen as a base for an objective assessment of FGA status on lakes (Table 3) by the various discriminant models were logical and had merit. Abundant FGA growth is correlated to lake acidification in general. It was felt that

variables related to lake acidity would be of prime importance in classifying lakes with varying amounts of FGA. Both Model 3 and Model 7 rejected lake morphometry variables (lake area, mean depth, see Table 3) in favour of water chemistry and geographic location variables for FGA classification purposes (Table 6). The latter variables are indicators for lake acidification in Ontario (Jones et al., 1990).

The models' application of lake acidification variables was done in a confusing manner, however. Both Model 3 and Model 7 would place lakes with positive axis scores into the NIL classification group for FGA. Lakes with more positive scores along Axis 1 of Fig. 3A (Model 3) would have greater pH and higher manganese, sodium and dissolved organic carbon concentrations according to the coefficients listed for each variable in Table 6. Those lakes would have a preponderance of characteristics related to non-acidified conditions and would be likely to actually have NIL FGA in reality (as often was the case, see Fig. 3A, circles). However, Axis 1 in both Model 3 and Model 7 contained a strong negative component for conductivity (Table 6). Lakes with high conductivity would tend to have negative axis scores, reversing the clear gradient of non-acidified lake characteristics corresponding to the right hand side of Fig. 3. The reverse trend allowed some lakes with high conductivity (often non-acidified lakes with NIL FGA) to be ordinated on the left in the scatter plot (Fig. 3, circles), where the models would predict them to be SOME lakes. The result was a relatively low success rate of FGA classification for both models. The explanation for this poor Model response may have been the failure to include some biological variables in the analyses. For example, macrograzer abundance may influence

FGA abundance in a manner contrary to that predicted by water chemistry alone (France & Welbourn, 1991). Alternately, the analyses could be run without including the conductivity variable to see if an improvement in classification accuracy would occur.

The results of the application of Model 3 to Database II highlighted watersheds 2D, 2E and 2H as "hotspots" of FGA growth. The Model 7 analysis on Database III reconfirmed those same three watersheds as the centre for FGA growth in the province and added four more watersheds (2C, 2K, 2L, 2M) to the list with an over 10% of lakes predicted to have noticeable FGA growths (SOME). The results are intuitively correct, as most of the seven watersheds (Fig. 1) have areas dominated by Canadian Shield outcroppings which hold lakes with poor buffering capacity and acidic precipitation has a greater effect in these watersheds in relation to other areas of the province (Jones et al., 1990).

A potential artifact may have influenced the results presented for the Model 7 analysis of the lakes in Database III. Model 7 contains the influence of Latitude in classifying lakes (Table 6). The model would consider more northerly lakes to be less likely to contain SOME FGA. The influence of latitude is valid for the small geographic area used to develop Model 7 (Database I), but may not hold for the much larger area encompassed by Database III (Fig. 5). The SOME group of lakes may be underestimated in the more northerly portions of Fig. 5.

The field verification of FGA growths on individual lakes was restricted to a relatively small

geographic range. All 44 of the 1988 helicopter survey lakes and all field surveyed lakes from previous years occurred within the boundaries of the Fig. 4 map. In the future, surveys should include more remote northerly lakes.

A substantial amount of missing lake water chemistry data prevented a proportion of the lakes from being used in the analyses (Tables 7 and 8). Future lake classification models should link recent water chemistry to recent known FGA status for more lakes in order to make the resulting predictions more accurate.

Our study provided an interesting example of the interaction of multi-disciplinary efforts in defining the extent of impact of a biological phenomenon (excessive FGA growth). Cottager perceptions of FGA growth were given credence by the statistical evaluation of cottager responses to carefully worded questionnaires. The perceptions were then used to guide an analysis of "hard" environmental data on physical and chemical lake characteristics for predicting FGA status of lakes. The power of each of these approaches to predict FGA abundance was significant, as verified by field sampling at all stages of the study.

The successful use of relatively untrained human observers for estimating aspects of limnological phenomena has been reported in the past. Young (1984) used realtors, local officials and water quality experts to rank the water quality at ten locations in a lake ranging from a polluted bay to a more pristine main lake site. Property values along the lake were

modeled via two equations, one utilized the human perceptions of water quality as a variable, the other utilized an objective measure of water quality. The decline in cash value of properties due to their proximity to poor water quality sites was nearly identical for both equations. Heiskary (1989) described the Lake Assessment Program in Minnesota which involved citizen volunteers in taking Secchi disk measurements and making subjective judgments on lake water quality by filling out questionnaire forms. The volunteer data were used to define the need for remedial action in specific ecoregions of the state (Smeltzer & Heiskary, 1990).

Overall, the results described here are illustrative of the potential capacity of statistical models to make meaningful predictions about biological phenomena. The types of models we have explored may be useful as a screening tool to identify lakes for more detailed study. The relative role of specific factors in the causality of FGA growths, however, is not addressed firmly by these models. More research is required to move from the classification and predictive levels illustrated in this study, to a better understanding of the causes of excessive FGA conditions.

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Table 1. Characteristics of the randomly selected subset of 178 lakes surveyed in 1986 for cottager perceptions of FGA growths across two stratification dimensions, acid sensitivity and completeness of water chemistry data.

Acid Sensitivity*	Completeness of available water chemistry data			
	Maximum	Moderate	Minimum	Total
1	1	0	1	2
2	16	12	9	37
3	32	17	28	77
4	16	9	5	30
5	16	3	13	22
Total	81	41	56	178

*alkalinity as μeq L^{-1}, 1 = <0; 2 = 0-40; 3 = 40-200; 4 = 200-500; 5 = >500

Table 2. Known filamentous algae status of the 32 reference lakes (1986 survey) organized according to lake acid sensitivity.

	Known FGA status		
Acid Sensitivity*	NIL	SOME	CONSIDERABLE
1	2	0	1
2	0	2	3
3	8	3	7
4	0	1	0
5	5	0	0

*as in Table 1.

Table 3. Variables (long list) used for discriminant analyses of Database I lakes.

Variable	Log_{10} Transformation	Name in analysis
Latitude*	no	LAT
Longitude*	no	LONG
Lake area*	yes	LGAREA
Maximum depth	yes	LGMAX
Mean depth	yes	LGMEAN
number of cottages / lake volume (m^3)**	yes	LGCDENSE
pH*	no	pH
total inflection point alkalinity*	yes	LGTIA
conductivity*	yes	LGCOND
colour	no	COLOUR
DOC	no	DOC
Sulphate	yes	LGN SO4
Calcium	yes	LGN CA
Magnesium	yes	LGN MG
Sodium	yes	LGN NA
Potassium	yes	LGN K
Aluminum	yes	LGN AL

Manganese	yes	LGN MN

*members of the short variable list; **an estimate of cultural eutrophication

Table 4. Overview of discriminant analysis models tested on Database I.

	Fine scale FGA classification (3 groups)	Coarse scale FGA classification (2 groups)
Long variable list	Model 1: 2 functions*	Model 3: 2 functions
	Model 2: 1 function	Model 4: 1 function
Short Variable List	Model 5: 2 functions	Model 7: 2 functions
	Model 6: 1 function	Model 8: 1 function

*a standardized canonical discriminant function is the equivalent of a scatterplot axis or Eigenvector, hence "2 function" can be read as "2 axis"

Table 5. Results of discriminant analysis models tested on Database I. Percentage of lakes correctly classified according to the original cottager classifications.

	Fine scale FGA classification (3 groups)	Coarse scale FGA classification (2 groups)
Long variable list	Model 1: 58% correct	Model 3: 66% correct
	Model 2: 52% correct	Model 4: same result as Model 3
Short Variable List	Model 5: 51% correct	Model 7: 65% correct
	Model 6: 48% correct	Model 8: same result as Model 7

Table 6. Standardized canonical discriminant function coefficients (Axis or Eigenvector compositions) for Model 3 and Model 7 as developed with Database I.

Model 3		Model 7	
Variable	Function 1	Variable	Function 1
pH	1.33764	pH	1.60368
LGN MG	1.33162	LAT	0.52712
LGN NA	0.80107	LGCOND	-1.13146
LAT	0.78830		
DOC	0.62132		
LONG	-0.59647		
LGCOND	-2.88939		

Table 7. Predicted incidence of FGA by watershed for the lakes in Database II.

Watershed	% of lakes with FGA accumulations	Number of lakes in the analysis (Model 3)
2D	27.0	37
2E	42.6	437
2H	40.3	144
2J	0.0	29
2K	4.6	87
Total	35.1	734*

*one lake was removed from the analysis because of incomplete data

Table 8. Predicted incidence of FGA by watershed for lakes in Database III.

Watershed	% of lakes with FGA accumulations	Number of lakes in the analysis (Model 7)
2A	0	258
2B	1.9	672
2C	22.9	446
2D	26.7	225
2E	57.5	922
2H	47.6	246
2J	7.7	220
2K	15.1	704
2L	20.0	10
2M	20.0	15
4C	0	37
4D	0	12
4F	0	18
4G	0	79
4J	0	239
4K	0	1
4L	0	350

4M	0	62
4N	0	8
5P	0	424
5Q	0	125
5R	0	25
Total	19.1	5,098*

*Total less than 5,276 because of incomplete data for some lakes

Table 9. 1988 field survey. Percentage of shoreline affected by FGA versus predicted by the Model 7 discriminant analysis.

Lake name	Lat. Long.	lake database*	% shoreline affected in 1988	Model 7 predictions**
Bear	4520 7842	I,II,III	2	S
Bentshoe	4502 7856	III	64	S
Blue Chalk	4512 7856	O,I,II,III	0	N
Buck	4525 7923	I,II,III	8	S
Clear	4511 7843	III	46	S
Clinto	4519 7852	I,II,III	15	N
Cradle	4528 7835	III	0	S
Crosson	4505 7902	II,III	0	S
Crown	4526 7840	I,II,III	72	N
Delano	4531 7836	III	0	N
Diamond	4523 7946	I,II,III	51	S
Dotty	4528 7900	I,II,III	12	N
Foote	4528 7911	I,II,III	0	N
Fox	4522 7921	II,III	22	S
Galla	4504 7952	I,II,III	44	S

Grindstone	4512 7853	I,II,III	38	S
Hamer	4514 7948	I,II,III	35	S
Harp	4523 7907	I,II,III	0	N
High	4514 7930	I,II,III	0	N
Hughes	4542 7934	I,II,III	41	S
Kimball	4521 7841	I,II,III	0	N
Leonard	4504 7927	O,I,II,III	6	S
Little Leech	4502 7901	I,II,III	34	S
Livingstone	4522 7843	I,II,III	0	N
Manitouwaba	4524 7942	I,II,III	77	S
Menominee	4512 7909	I,II,III	1	S
Myers	4506 7945	I,II,III	18	S
Pincher	4534 7851	III	47	S
Pine	4504 7904	I,II,III	0	S
Plastic	4511 7850	III	56	N
Prospect	4459 7908	I,II,III	0	S
Ril	4510 7900	I,II,III	22	N
Round	4528 7924	I,II,III	2	S
Rutter	4515 7931	I,II,III	55	S
Salmon	4515 7958	O,I,II,III	49	N
Shoe	4512 7855	I,II,III	1	S
Skidway	4512 7952	III	64	S

Spring	4501 7908	I,II,III	0	S
Sugar	4522 7946	I,II,III	23	S
Toad	4526 7856	I,II,III	37	S
Tock/Otter	4516 7853	I,II,III	79	N
Westward	4529 7847	III	0	N
Wolf	4526 7842	I,II,III	76	N
Young	4513 7933	II,III	2	N

*O = one of the original 10 lakes in the 1985 survey; I = one of the lakes from water chemistry Database I; II = member of water chemistry Database II; III = member of water chemistry Database III

**N = nil (≤5% shoreline affected); S = some (>5% shoreline affected)

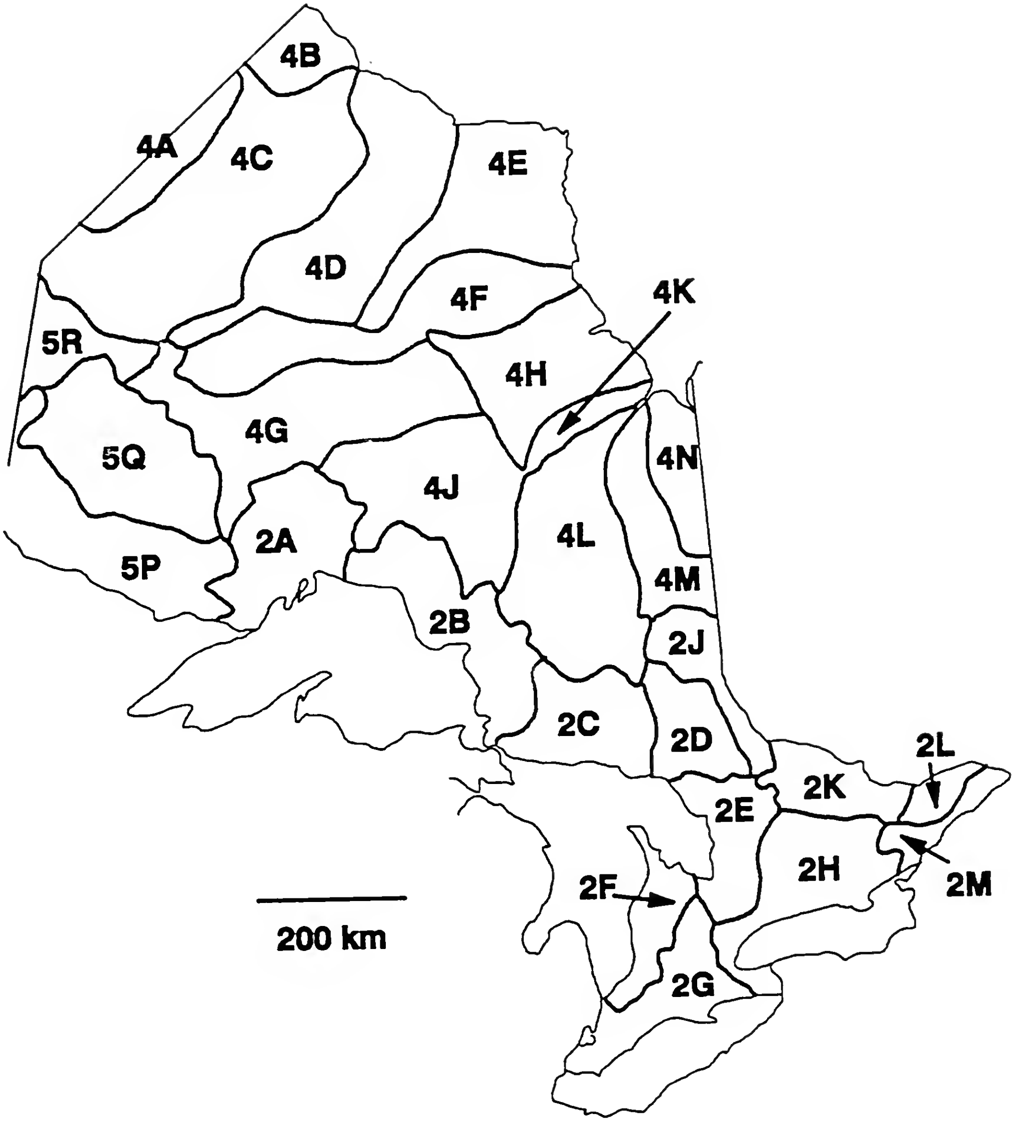
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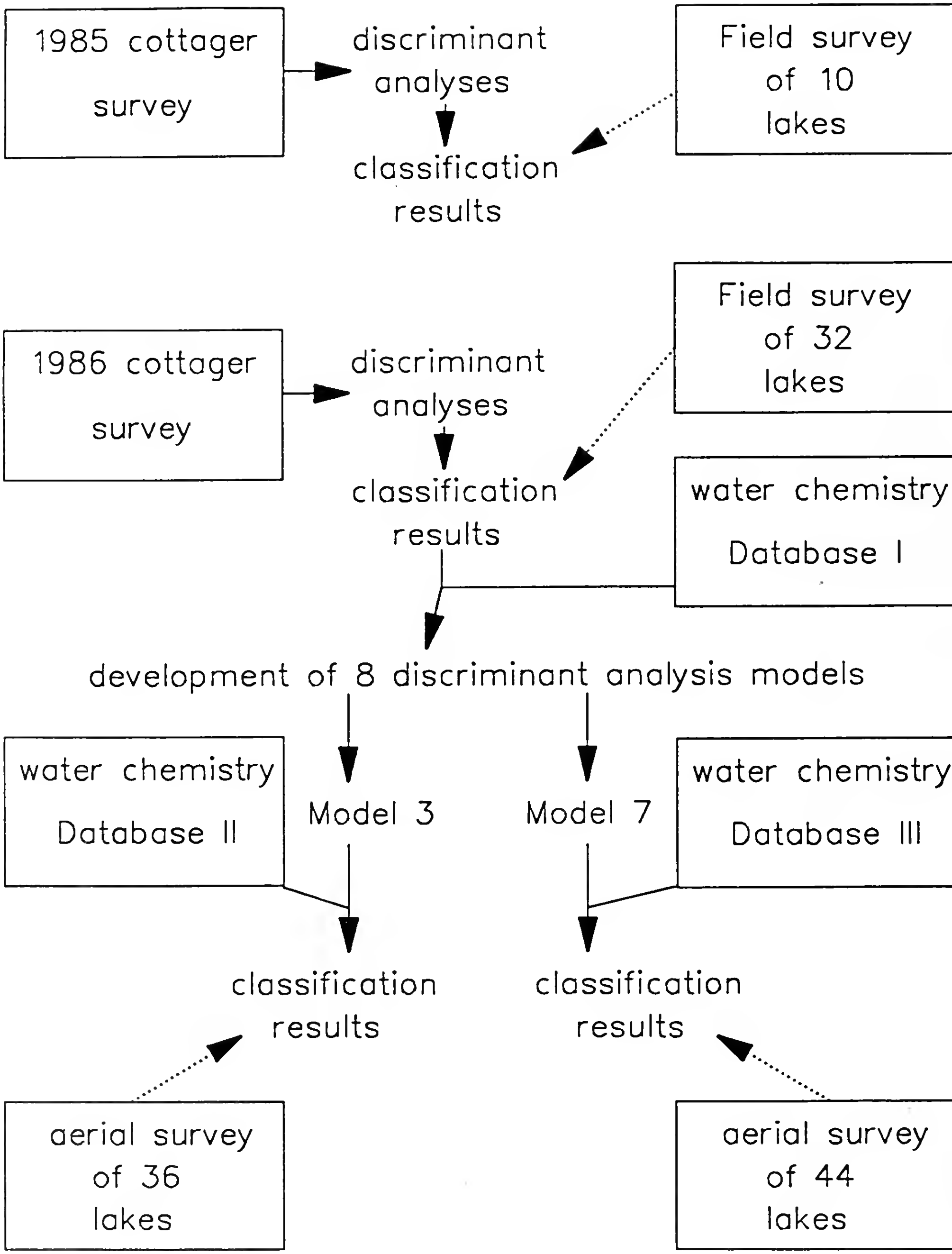
Fig. 1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discriminant analyses
Field survey of 10 lakes
classification results
Field survey of 32 lakes
1986 cottager survey
discriminant analyses
classification results
water chemistry Database I
development of 8 discriminant analysis models
water chemistry Database II
Model 3
Model 7
water chemistry Database III
classification results
classification results
aerial survey of 36 lakes
aerial survey of 44 lakes

Fig. 2

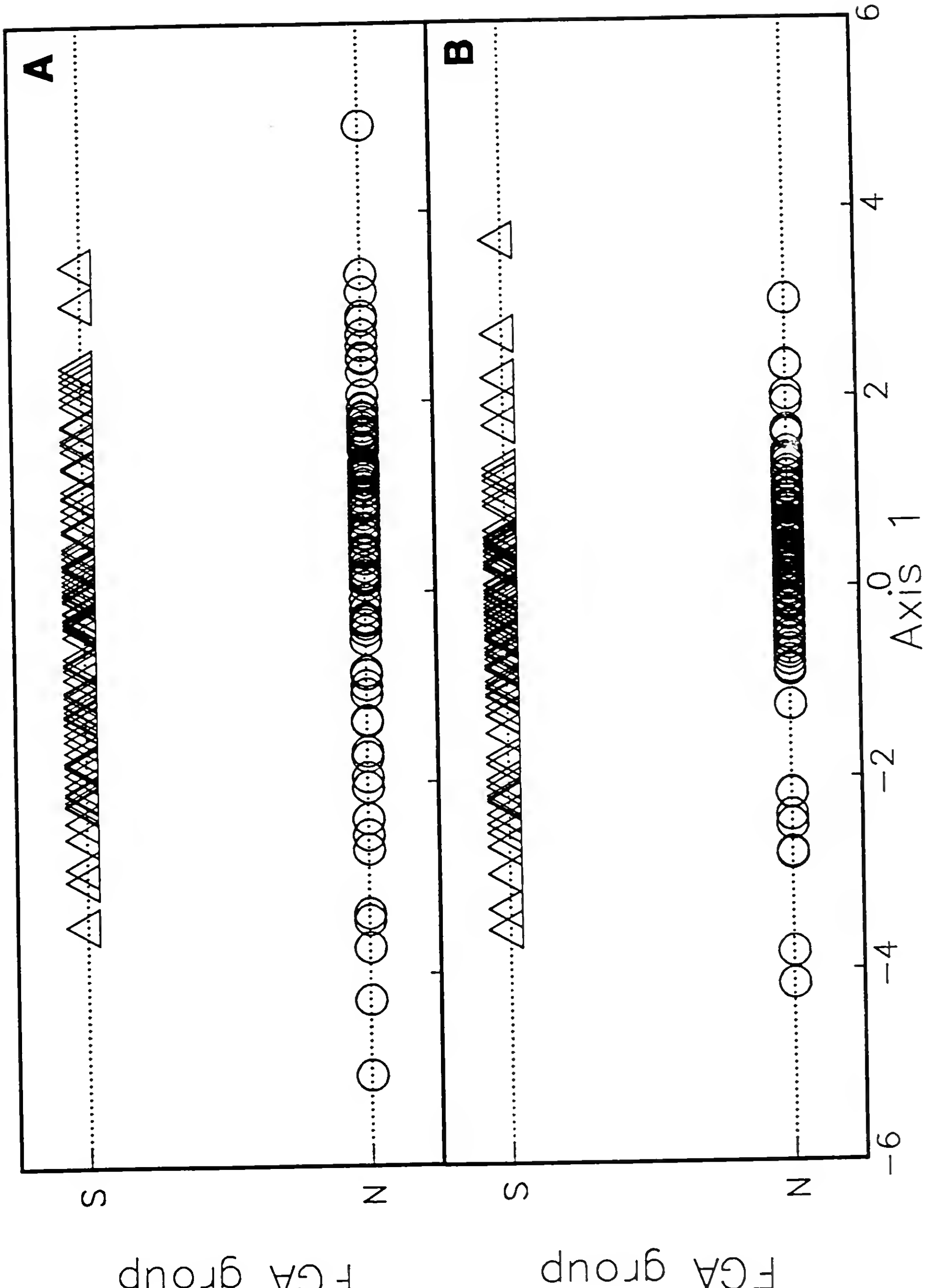

Fig. 3

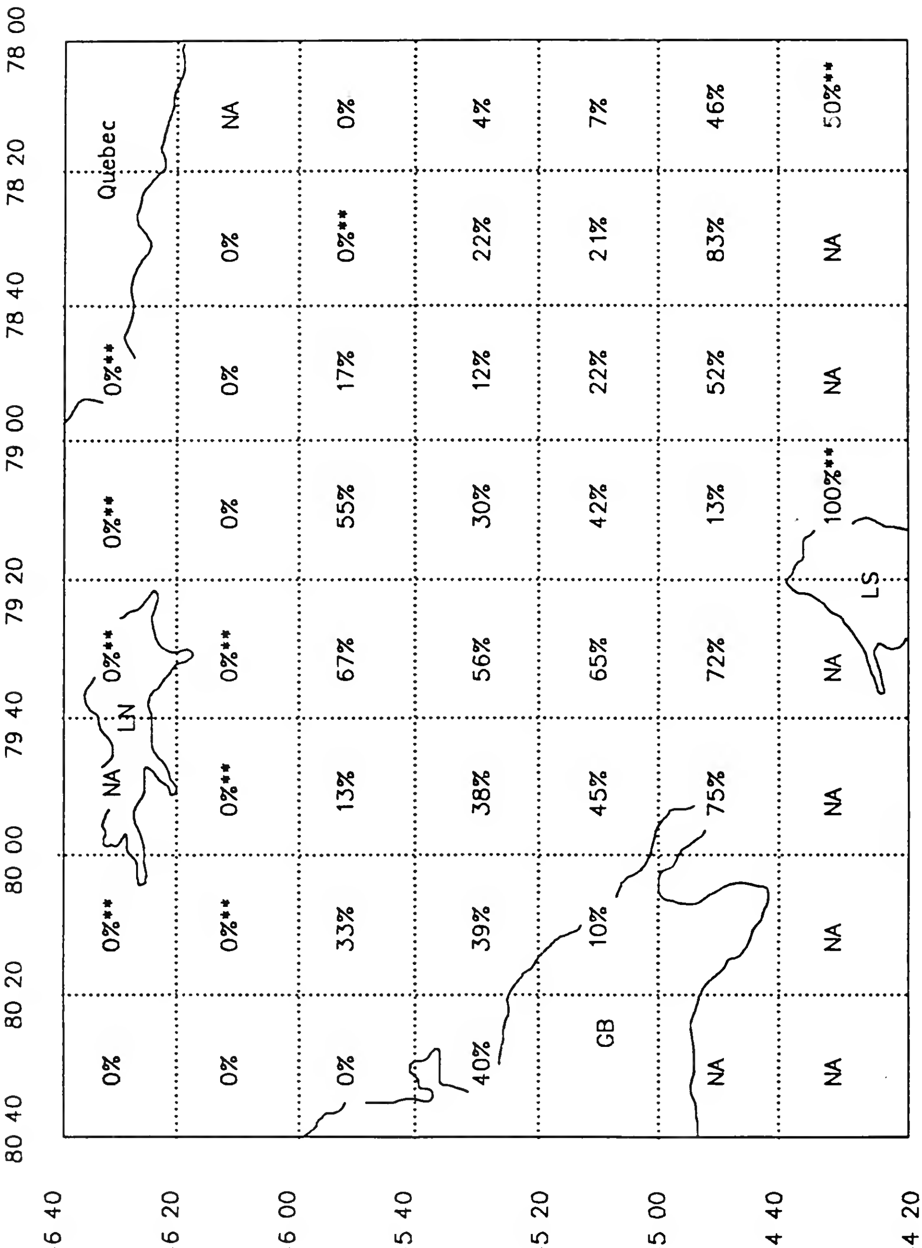

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Fig. 4

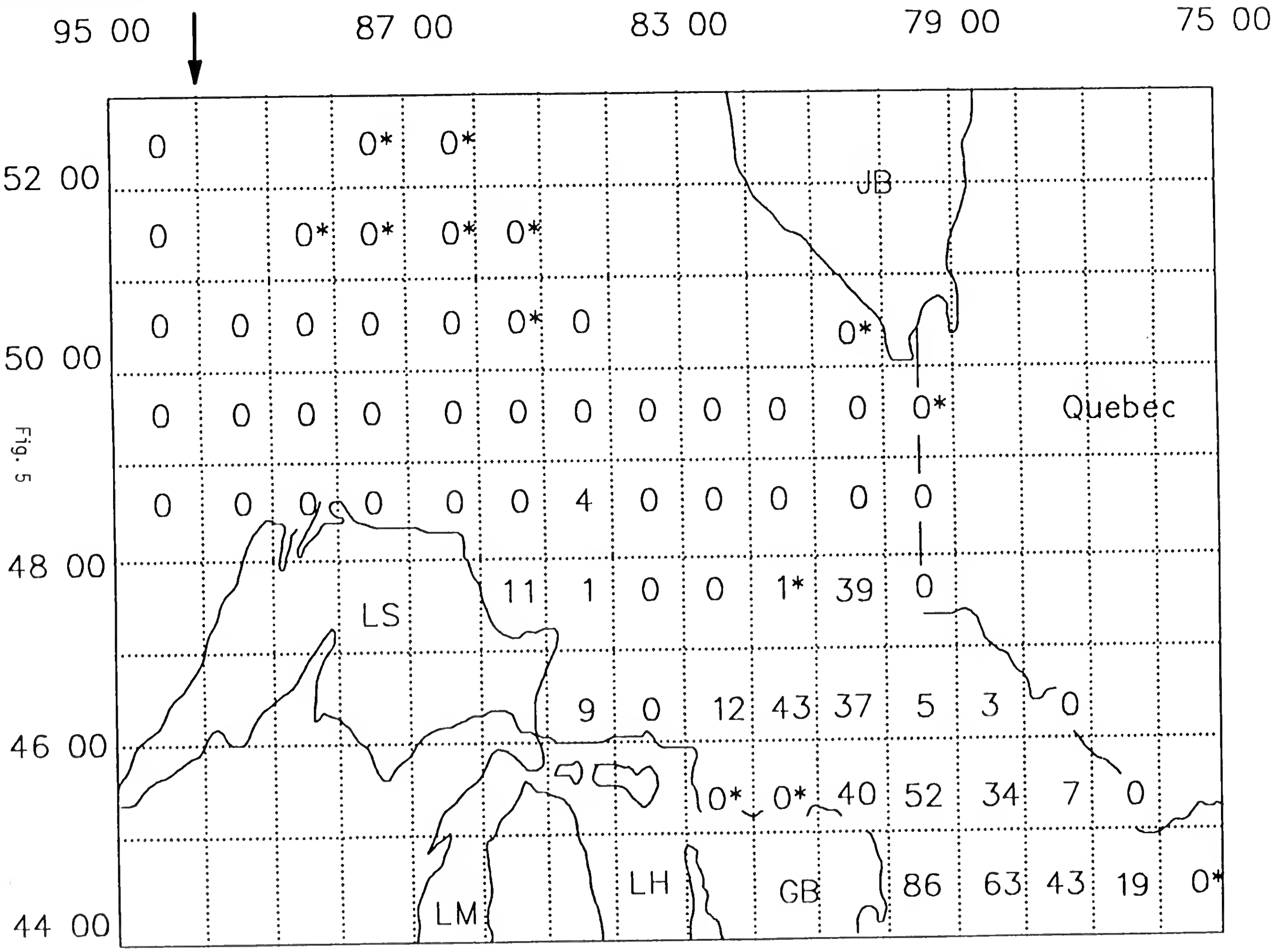
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Fig. 5